**Question: How big would Colorado be if you took a rolling pin and flattened out the State to be 1 inch thick? What approach would you use?**

Several USGS staff members with expertise in remote sensing and geospatial analysis were asked to see how they would approach finding the solution to this question using data collected and maintained by the USGS through the 3D Elevation Program.

The 3D Elevation Program began in 2016, and is a multi-million dollar partnership between the USGS, other Federal, State, and Local entities, and the private sector. The goal of the 3DEP is to ensure complete and consistent high resolution elevation coverage across the Nation. At the end of 2023, the USGS has 95% coverage (in progress or available) of 3DEP quality data across the Nation. Lidar is the primary technology used for collecting elevation surfaces in the lower 48 states, islands, and territories, with a 3D radar imaging technique (IFSAR) being used as the main technology in Alaska. The USGS coordinates acquisition of this data with our public and private sector partners, provides quality assessments on the delivered data, and produces standard USGS 3DEP Products at various resolutions. All products and source data are available online from various sources for visualization and download.

There are many valid approaches that can be taken to answer this question, there is no single “right” method. For this exercise, our team will use a publicly available standard USGS raster product built from 3DEP quality lidar collected over Colorado. The raster we will be using is our 1/3\textsuperscript{rd} Arc Second product, which has a ground sample distance of approximately 10 by 10 meters, with trees and buildings removed. Phrased differently, for a 10m by 10m square on the ground, you will have a common value that reflects ground elevation (aggregated by area) across the entire state. We chose this product for speed, it will be a faster process than using a higher resolution elevation model, while still maintaining good levels of accuracy (versus using a lower resolution elevation model).

We will limit our analysis to the political boundary of the state of Colorado, maintained by the USGS. Our team will place the digital elevation and boundary in a common coordinate reference system and projection. There are many map projections that can be used for this exercise, each have strengths and weaknesses (think of the many different types of maps you see and different representations of shapes and distances. We have chosen to use a fairly standard national coordinate system and projection for Colorado in this exercise. Keep in mind the estimate will change based on the different types of systems we choose to use. Our team will conduct analysis of the data in a Geographic Information System (GIS) application, which will allow us to determine the total volume of land in the state above a plane of approximately 3,000 feet above sea level – near to the minimum elevation in Colorado. Since the goal is to understand the surface area of Colorado flattened to a depth of 1 foot, we will use the volume of the total land mass above approximately 3,000 feet to calculate final area.

**Method:**

Colorado has the highest mean elevation (6,800 ft) and the highest low point (3,317 ft) in the United States (Wikipedia, 2024). Although many people view Colorado as a rectangle, it is closer to an isosceles trapezoid. However, due to surveying errors that were adopted into the official border, Colorado is actually a hexahectaenneacontakaiheptagon (697-sided polygon) (Jacobs, 2023).
Simplistically, and in three-dimensions, Colorado would be a rectangular prism or a trapezoidal prism. The volume of both shapes would be the 2D area multiplied by the height. If we use a 2D area of 104,094 square miles (269,601 square kilometers) (U.S. Census Bureau, 2010) and multiply it by the Colorado mean height of 6,800 ft (2072.64 meters), we will get a total volume of 134,059.85 cubic miles (558,785.82 cubic kilometers) of earth. Setting the reference plane as the lowest point in Colorado (approximately 3,317 ft), the total volume would be of 68,503.35 cubic miles (285,534.42 cubic kilometers).

For this exercise we are using 3D Elevation Program data and calculating the volume of the bare-earth elevation surface in the State of Colorado above either a reference plane at the lowest point in Colorado (3,317 ft) or from sea level. Either method would require the same data prep.

First, we downloaded USGS 1/3 Arc-Second Digital Elevation Models (DEMs). This layer is the highest resolution spatially-integrated bare-earth DEM dataset of the US with full coverage of the 48 conterminous states, Alaska, Hawaii and U.S. territories (U.S. Geological Survey, 2024). There are a total or 1,439 1-degree by 1-degree tiles that make up the USGS 1/3 Arc-Second dataset. 47 of those tiles intersect the state of Colorado completely or partially.

![Figure 1](image)

**Figure 1.** USGS 1/3 Arc-Second Seamless DEM tiles (in green) and the State of Colorado (in red).

We merged those 47 DEM tiles together and re-projected them from geographic angular decimal degree measurements into a planar coordinate reference system that is optimized for area calculations. In this case, we used North American Datum of 1983 Universal Transverse Mercator Zone (UTM) 13N and set a cell size of 10 meters.¹

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¹ We also used the USA Contiguous Albers Equal Area Conic projection for comparison but determined the UTM Zone 13 projection area more closely matched the official US Census Bureau area for Colorado.
Next, we ran a process that ensured the new raster dataset matched the extent of an available Colorado boundary feature class. This creates a DEM surface that has the gridded height above sea level (in North American Vertical Datum of 1988) in meters for every 10-meter by 10-meter cell in Colorado. This height represents the average bare-earth height for each cell and does not include surface features such as buildings or trees.

**Figure 2.** A shaded relief representation of the merged USGS 1/3 Arc-Second Seamless DEM data clipped to the State of Colorado.

Finally, we calculated the volume for every pixel shown in the image above, using our baseline elevation (minimum height of Colorado) for the entire surface in a GIS application. USGS does not endorse any specific software for this exercise, it can be done in many different GIS applications.

The lowest height in our DEM surface is 1,013.54 meters. We set that as the reference plane height and the tool calculated the volume of earth in Colorado in cubic meters above the lowest point in Colorado. In essence, it took every 10-meter by 10-meter elevation pixel value height and subtracted 1,013.54 to get a normalized height above the reference surface. This normalized height was summed for every pixel in the image, a total of 2,821,373,368 (2.8 billion) cells in Colorado. That gave us a volume of 290,709,703,022,630 (290.7 trillion) cubic meters, or 10,266,316,274,947,100 (10.2 quadrillion) cubic
feet.² The total volume in cubic miles would be 69,744.97 which is very similar to of the 68,503.35 cubic miles estimate we generated by multiplying the area of Colorado by the average height of 6,800 feet.

If we flatten Colorado to be 1 inch thick, the surface area would equal the volume (10,266,316,274,947,100 cubic feet) divided by the height (1 inch = 1/12 of a foot). That would make the surface area of Colorado equal to 4,419,041,096.31 (4.4 billion) square miles. That is approximately 42,452 times larger than the normal Colorado area of 104,094 square miles.

Figure 3. An oblique shaded relief representation of the merged USGS 1/3 Arc-Second Seamless DEM data. Subset of the state of Colorado.

References


² We ran the analysis a second time to calculate the volume in cubic meters above sea level but determined that Colorado Public Radio was fine with calculations that used the lowest point in Colorado as the base reference surface.